

The Ocean's Role in Climate

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My name is Raymond Schmitt, I am a Senior Scientist in the Department of Physical Oceanography at the Woods Hole Oceanographic Institution. My research interests include the ocean's role in climate, small-scale mixing processes, the global water cycle, and instrumentation for a global ocean observing system. I have served on a number of national and international committees concerned with climate, including the Atlantic Climate Change Program Science Working Group, the Ocean Observing System Development Panel, and the Climate Variability (CLIVAR) Science Steering Group, and am a contributing author to the IPCC Third Assessment Report.

The thrust of my comments today is that the crucial role of the oceans in climate has not been sufficiently acknowledged in most research on climate change to date, including the National Climate Assessment Report under discussion here. It was a tradition of the climate modeling community to treat the ocean as a shallow swamp; a source of moisture but playing no role in heat transport and storage. We now know this to be a significant error, the oceans are an equal partner with the atmosphere in transporting heat from the equator to the poles, and a reservoir of heat and water that overwhelmingly dwarfs the capacity of the atmosphere.

A few facts about

The Oceans:

Cover 70% of the surface of the Earth.

Have 1,100 times the heat capacity of the atmosphere
(99.9% of the heat capacity of the Earth's fluids)

Contain 90,000 times as much water as the atmosphere
(97% of the free water on the planet)

Receive 78% of global precipitation

A quote from Arthur C. Clarke gets it right:

"How inappropriate to call this planet Earth when clearly it is Ocean"

--Nature, v. 344, p 102, 1990.

New evidence for the essential role of the oceans in climate is coming out of the recent World Ocean Circulation Experiment (WOCE), supported by the National Science Foundation. A globe-spanning set of ship-based observations in the '90s revealed that the depths of the ocean had warmed significantly since previous observations in the '50s. In fact, about half the "missing" greenhouse warming has been found in the ocean. It was missing because models had projected a larger increase than had been observed. It now appears this was because they had not properly accounted for the capacity of the oceans to store large quantities of heat on short timescales. In fact, it is easy to calculate that if all of the extra heat due to the greenhouse change in the radiation balance were to be deposited in the deep ocean, it would take 240 years for it to rise 1°C. Thus, monitoring the ocean's patterns of heat storage is absolutely essential for understanding global warming, yet we have no system for such observation

But the oceans do more than simply delay global warming. Research over the past twenty years has brought a growing appreciation of how the slow movement of warm and cold patches of ocean water can affect our weather for months at a time.

The alternating influence of El Niño and La Niña are now well known to the public and are rashly blamed for any type of unusual weather. These 3-5 year period disruptions in weather patterns are caused by the movement of warm water in the tropical Pacific, and are now predictable up to a year in advance because of a special monitoring network of ocean buoys maintained there. The influence of El Niño on US weather is well publicized, but it actually explains only a small part of the variation in temperature and rainfall over the United States.

Some other natural ocean climate cycles known as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) can explain much more of the variability in winter-time weather than El Niño.

(Figure 1.). The NAO

Exciting new findings suggest that the ocean controls the timescale of the NAO, thus holding out the hope that these weather patterns will be predictable when sufficient ocean observations become available.

Figure 1. The correlation of US winter-time climate with El Nino, PDO and NAO over a 35 year period. If we could predict these phenomena in advance, then the square of the numbers represented by the colors gives the winter climate variability that is potentially predictable. That is, white areas would have no predictability, but in the brown areas 36% or more of winter climate changes could be predicted. However, we do not yet have predictive capabilities for PDO or NAO. If predictions are to be made we will require a greatly expanded ocean observing system.

Recent research indicates that the NAO's changes in atmospheric pressure patterns over the Atlantic are linked to the slow variation in water temperatures, as the ocean currents rearrange the warm and cold ocean patterns that serve to guide the atmosphere in its preferred modes of oscillation. Only the ocean has the long-term memory to provide the decadal time scales observed in the NAO. An understanding of these natural modes of climate variation is essential for accurate predictions of the regional trends in US climate. That the two models examined in the Climate Assessment report should differ so widely in prediction of future US precipitation is no surprise. Models are only a repository for what we think we know, and an understanding of the important oceanic phenomena such as PDO and NAO has not yet been achieved. In order to understand these phenomena we need to observe the motion of the deep warm and cold patches that give the ocean its multi-decadal memory, and we need to sustain those obser

Figure 2. The North Atlantic Oscillation (NAO). Its "high index" state is shown on the left, this corresponds to particularly high atmospheric pressure over the Azores, an intense low over Iceland. Ocean winds are stronger and winters milder in the eastern U.S. When the NAO index is low, ocean winds are weaker and the U.S. winter more severe. Changes in ocean temperature distributions are also observed.

The Water Cycle and Thermohaline circulation

Also, satellites can tell us nothing about the salt content of the ocean, which reflects the workings of the water cycle. There is an increasing attention to the importance of the water cycle in global change; for most communities drought or flood are more pressing challenges than a few degrees of warming. However, there has been little recognition that most of the water cycle occurs over the oceans. It would take a diversion of only 1% of the rainfall falling on the Atlantic to double the discharge of the Mississippi River. Water travels quickly through the atmosphere, spending only about 10 days on a short ride from one spot to another. Water molecules spend thousands of years on the slow return flow in the ocean. But the process of water leaving the surface of the ocean, and thereby changing its salt content and density, drives an interior flow many times larger than the flux of water due to evaporation and precipitation alone. This "thermohaline circulation" is a key element of the climate system.

Figure 3. The influence of salt content (salinity) on the process of deep convection. Normally, winter cooling at the surface causes deep vertical mixing which releases much heat to the atmosphere (left). When fresher water lies at the surface because of rain fall or ice melt, the deep convection is prevented and only a shallow surface layer provides heat to the air above (right). Thus, salinity is now considered a key variable for climate studies.

Records from ocean sediments of the fossils of marine life indicate that this has happened many times in the past, with dramatic consequences for climate over a large area. The most recent event was about 12,000 years ago, when the freshwater from melting glaciers shut down the thermohaline circulation in the North Atlantic. This had dramatic consequences for the North Hemisphere, returning much of it to glacial conditions for 1000 years. The data indicate that this happened rapidly, in only a decade or two. Some models predict that such abrupt climate change could happen again as the water cycle intensifies with future global warming. However, such transitions in the thermohaline circulation have been shown to depend on the rate of interior mixing in the ocean, and we know that this is incorrectly treated in the present generation of climate models.

Model Deficiencies

In fact, oceanographers have many complaints about how poorly climate models simulate the ocean. Because of computer limitations, they must treat it as a very viscous fluid, more like lava or concrete than water. Such models fail to simulate the real ocean's changes in deep temperatures. We know that the "sub-grid-scale" parameterizations for mixing processes are incorrect, reflecting none of the observed spatial variations or differences between heat and salt. This mixing drives the interior flows in the ocean. We know that the processes by which ocean currents give up their momentum are incorrectly treated. And these are not problems that will quickly yield to increased spatial and temporal resolution in the computer models. Even if computer power continues to increase by an order of magnitude every 6 years, it will be over 160 years (1) before models have the resolution necessary to simulate the smallest ocean mixing processes! Society cannot afford to wait that long. We will not come to an

Observing deficiencies

While we have in place a system for monitoring El Nino, we have no such ability to observe the motions of thermal anomalies in the mid- and high latitude oceans. Nor do we monitor the salt content of ocean currents, to determine the potential for deep convection or to help understand the vast water cycle over the oceans. But new technology, the vertically profiling ARGO float (Figure 4.), promises to give us the data we need to begin to understand this largest component of the global water cycle. These are like weather balloons for the ocean, drifting at depth for 10 days then rising to the surface to report profiles of temperature and salinity to a satellite. They then resubmerge for another 10 day drift, a cycle to be repeated 150 times or more. The distance traveled between surfacings provides a measure of the currents at the depth of the drift. The ARGO program (<http://www.argo.ucsd.edu/>) is an international plan to maintain a global distribution of ~3000 floats as a core element of a Global Ocean

Figure 4. The operation of a profiling float for the ARGO program. These autonomous probes can provide unprecedented amounts of data from the interior ocean at a modest cost. Knowledge of the interior ocean temperature is necessary because these waters interact with the atmosphere every winter through the process of deep convection.

Figure 5. The surface salinity of the global ocean is represented by the colors, with red being the saltiest and blue/purple the freshest. 3000 random dots, representing possible ARGO float positions, are seen to provide good sampling of the large-scale patterns of salinity variation. The Atlantic Ocean is seen to be saltiest, which helps explain why deep convection is especially likely there, and its important role in the thermohaline circulation.

What can Congress do?

1. Support fundamental research into the processes that govern the ocean's role in climate. This includes the basic oceanic research programs at NSF and ONR, and international programs like CLIVAR.
2. Make a substantial and long-term commitment to the creation of a Global Ocean Observing System. Fund the ARGO program at NOAA (Ocean Observations component of Climate Observations and Services) and the ocean observing satellites of NASA.

Summary:

Policy makers would like climate scientists to produce firm predictions. However, they must always remember that science is the process of testing ideas against facts and access to quantitative data is essential to the process. The ocean is a crucial element of the climate system, yet its "subgrid-scale" processes are too poorly understood and its basic structure too poorly monitored, to provide much confidence in the details of present day predictions.

The National Climate Assessment Report is a good faith effort to assess the effects of global warming on US climate; the regional disagreements of the two available models are to be expected, given our poor understanding of the ocean.

Global warming due to the effect of greenhouse gases on the radiation balance

is as certain as the law of gravity, but the issues of how rapidly heat is sequestered in the oceans, its impact on the water cycle, and the important regional variations in climate, remain very challenging research questions.

Climate prediction is a hard problem, but appears to be tractable. An abundance of evidence indicates that the key to long-term prediction is in the workings of the ocean, which has 99.9% of the heat capacity of Earth's fluids. It is the heart of the climate "beast", the atmosphere its rapidly waving tail, with only 0.1% of the heat capacity. Let us get to the heart of the matter, with an unprecedented new look at the ocean. We have the technical capabilities. The cost is modest. The payoff is large. The society that understands long-term climate variations will realize tremendous economic benefits with improved predictions of energy demand, water resources and natural hazards, and it will make wiser decisions on issues affecting the habitability of the planet, such as greenhouse gas abatement.

Note:

(1) It will take a factor of 10^8 improvement in 2 horizontal dimensions (100 km to 1 mm, the salt dissipation scale), a factor of 10^6 in the vertical dimension (~ 10 levels to 10^7) and $\sim 10^5$ in time (fraction of a day to fraction of a second); an overall need for an increase in computational power of $\sim 10^{27}$. With an order of magnitude increase in computer speed every 6 years, it will take 162 years to get adequate resolution in computer models of the ocean.